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THE DISTRIBUTION AND ABUNDANCE OF THE JAPANESE BEETLE FROM 1944 THROUGH 1949

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The distribution and abundance of the Japanese beetle (Popillia japonica Newm.) through the summer of 1943 has been discussed by Hawley and Dobbins.[1/] Since that time the area infested by the insect has increased more than one-half and there have been great fluctuations in numbers, due largely to climatic influences. The changes in the status of the beetle in the years from 1944 through 1949 are discussed in this paper.

The area infested by the Japanese beetle may be divided into two main parts. In one, known as the area of general distribution, the insect may be found wherever conditions are suitable, there being no extensive uninfested areas. In the other, known as the outer zone, the insect occurs in varying numbers at isolated points, which are separated from the area of general distribution and are often some distance from one another (fig. 1). It is with changes in the area of general distribution that this paper will largely deal. The outer limit of this area is scouted each year by personnel of the Moorestown, N. J., laboratory of the Bureau of Entomology and Plant Quarantine and cooperating entomological workers in the States involved. State workers send reports on beetle conditions to Moorestown and, when all the information has been received, a report covering the entire infested area is prepared and a map is drawn showing the limit of spread and the relative abundance of the insect in different parts of the area. The maps used in this paper were prepared from these reports. Scouting to determine beetle abundance is also carried on by the Division of Japanese Beetle Control of the Bureau, and the data obtained in this survey are also used in preparing the final report. Information on the status of the insect in the outer zone is obtained largely in the trapping and regulatory activities of the Division of Japanese Beetle Control.

1/ Hawley, I. M., and Dobbins, T. N. The Distribution and Abundance of the Japanese Beetle From 1935 Through 1943, with a Discussion on Some of the Known Factors That Influence Its Behavior. N. Y. Ent. Soc. Jour. 53: 1-20. 1945.

CHANGES IN THE AREA OF GENERAL DISTRIBUTION

In 1943 the area of general distribution of the Japanese beetle was estimated to be 29,200 square miles. All of two States, parts of six others, and the District of Columbia were included. By 1949 this area had grown to 47,910 square miles and two additional States had been invaded. The area infested in the differen States during the 6-year period covered by this paper is shown in table 1, in which the States are arranged in the order in which they became infested. The area infested up to 1930 and the changes by 3-year periods thereafter through 1948 is shown in figure 2.

Each year there is a natural dispersion around the thinly infested fringe of the area of general distribution, the extent of which varies with the type of terrain encountered and weather conditions. Larger increases in the area of general distribution occur when isolated infestations in the outer zone grow in size, meet, and join the generally infested area. There have been several additions of this type in the 6-year period ended in 1949. Beetle dispersion is always most rapid through level country and up river valleys, and slowest through woody or mountainous terrain, as will be brought out in discussing the changes in recent years.

Table 1.--Increase in size of area of general distribution of the Japanese beetle, by States, from 1944 through 1949.

State	Estimated infested area (Square miles)					
	1944	1945	1946	1947	1948	1949
New Jersey	8,224	8,224	8,224	8,224	8,224	8,224
Pennsylvania	8,327	8,327	9,097	9,467	10,597	12,902
Delaware	1,965	1.965	1,965	1,965	1,965	1,965
Maryland	6,762	6,762	7,557	7,857	8,027	8,402
New York	3,352	3,652	4,458	5,038	5,163	5,313
Connecticut	2,401	2,401	3,025	3,795	3,970	4,390
District of Columbia	62	62	62	62	62	62
Virginia	1,432	1,432	2,092	2,292	3,217	3,757
Massachusetts	210	210	400	955	1,485	1,575
West Virginia	165	165	365	515	530	550
Rhode Island			255	580	710	770
Total	32,900	33,200	37,500	40,750	43,950	47,919

As may be seen in figure 3, all of Delaware, New Jersey, and the District of Columbia were generally infested by 1944. By this time a large isolated tract, which in 1943 included parts of western Maryland, northern Virginia, and eastern West Virginia, had joined the area of general distribution. This was the first extension of the continuously infested zone into West Virginia. By 1944 there had

been considerable dispersion up both the north and west branches of the Susquehanna River in Pennsylvania, and in New York there had been a spread up the valley of Hudson River to a point above Kingston. Scouting on Long Island showed that several infestations along the south shore had united and that the entire eastern end of the island had become infested, but that some of the northern and central parts were still free of beetles. There were several infestations along the southeastern shore of Connecticut as well as at Providence and other places on Narragansett Bay in Rhode Island which were still separated from one another and from the area of general distribution.

There was little scouting to determine the spread of the Japanese beetle in the summer of 1945. The only marked change noted was a spread along the north shore of Long Island, which left only one small area in the center of the island still uninfested.

By the summer of 1946 the infestations in southeastern Connecticut and Rhode Island had united and joined the area of general distribution (fig. 4). Rhode Island was thus included in that area for the first time. In Massachusetts beetles had spread up the valley of the Connecticut River beyond Northampton, and in New York they had moved up the Hudson River Valley as far as Albany. Along the north branch of the Susquehanna River in Pennsylvania a large infestation centering about Wilkes-Barre had been spreading down the river but had not yet reached the area of general distribution. Beetle dispersion reached the southern rim of the Appalachian Mountains in Pennsylvania about 1940, but penetration of this barrier was slow. Scouting in 1946 showed that beetles had finally moved through several of the gaps in this range and were present on the other side. Mountain ranges of this type slow down dispersal but do not stop it. The small area in central Long Island, which had been free of beetles in 1945 became infested in 1946. There had been a westward movement of beetles in Maryland and West Virginia, which added a great deal of territory to the area of general distribution. Several isolated infestations in Virginia are outlined on the 1946 map; these have their centers at Fredericksburg, Washington's Birthplace, Norfolk, and Richmond.

As is evident from figure 5, there had been considerable spread of the Japanese beetle in eastern Massachusetts by 1947. The movement up the Connecticut River in this State had then reached beyond Greenfield. In New York there had been a spread up the Hudson River beyond Albany to include Troy and up the Mohawk River to a point beyond Schenectady. In Orange and Ulster Counties in southeastern New York beetles had moved up the valleys of several small streams and encircled a tract of high and woody land still free of beetles. The large infested tract on the north branch of the Susquehanna River was still separated from the area of general distribution by several miles of beetle-free territory. The probable outline of an infestation near Chambersburg, Pa., is shown on the map for 1947.

Scouting in Massachusetts in 1948 showed that the area of general distribution had reached a point just south of Boston (fig. 6), and that the spread to the east was greater than that shown on the map for 1947. Beetles were found almost to the Massachusetts-Vermont State line in the Connecticut River Valley. The

large infestation on the north branch of the Susquehanna River in Pennsylvania joined the area of general distribution in 1948 and the spread to the southwest brought in the infestation about Chambersburg. The southern extension of the area of general distribution in Virginia brought about a union with the infestation about Fredericksburg. A new isolated infestation that originated in Washington, Va., is shown on the 1948 map.

In 1949 (fig. 7) there was a large increase in the generally infested area in eastern Pennsylvania, and with beetles occurring continuously from Mount Pocono to Scranton, a large uninfested area became entirely surrounded by beetle-infested territory. There was also an increase in the infested area in Virginia when the spread of the beetle from near Fredericksburg joined an infestation along the Potomac River centering about Washington's Birthplace, and when the spread to the southwest reached and joined an infestation around Washington, Va.

In the early years of its establishment in this country the Japanese beetle had a more or less uniform spread each year from the introduction point in central New Jersey. Barriers of various kinds have since been encountered that have influenced the rate of dispersion. The rapid spread up the valleys of the Connecticut, Hudson, Susquehanna, Delaware, and Potomac Rivers is evident on recent distribution maps. Mountainous terrain in Pennsylvania has retarded, but has not prevented, beetle dispersion there. In central New England dispersion has been slower than farther south because of the effect of the cool climate on beetle activity. However, there is no evidence that any physical or climatic barrier now known will stop the growth of the area of general distribution for some time to come. The rate of spread will doubtless vary in different parts of the area, but some spread must be expected in all directions each year.

CHANGES IN BEETLE ABUNDANCE IN THE AREA OF GENERAL DISTRIBUTION

As the Japanese beetle spreads into a new area, there is usually a gradual increase in numbers for several years until a more or less stable condition is reached; from then on there will be year-to-year fluctuations in numbers brought about by the action of climatic and biotic influences. The amount of summer rainfall is the most important climatic influence in changing beetle populations. It is pointed out in a paper by Hawley [2] that if rainfall during the summer months, when eggs and small larvae occur in the soil, is below normal, fewer beetles may be expected the following year; if rainfall is normal or above an increase in numbers usually occurs. The distribution of rainfall in the three summer months is often uneven; it may be normal or above in one month and less than usual in the other two. In most of the infested area a drought in July is most destructive to the soil-inhabiting stages because more eggs and small larvae are present at this time; in the extreme northern range of the beetle a lack of rain in August or September is important because of the more retarded development of the soil population there.

2/ Hawley, I. M. The Effect of Summer Rainfall on Japanese Beetle Populations. N. Y. Ent. Soc. Jour. 57: 167-176. 1949.

The area infested by the Japanese beetle is now so large that it is possible for rainfall to be deficient in one part of it and excessive in another. Summer rainfall often occurs in the form of thundershowers, which may be heavy in one place and light or wanting in nearby places. Uneven rainfall of this type can have an important influence on beetle abundance.

The type-A milky disease of Japanese beetle larvae caused by Bacillus popilliae is the most important biotic influence on beetle abundance. It was first found in the Philadelphia area about 15 years ago. Since that time it has spread to or been introduced into most of the beetle-infested area. When once established, the bacterial pathogen that causes this disease continues to increase in numbers and effectiveness and causes an ever-mounting mortality of the grub population. It is not unusual for half, or more, of the larvae in a brood to die from this disease. When larvae are killed by milky disease, the spores that were in the body remain in the soil, and when ingested by other grubs with their food, attack and kill them. When the larvae are abundant, more of them contract the disease, and the soil content of disease spores increases more rapidly.

The action of milky disease is briefly treated in a paper by Hadley. 3/ It is pointed out in the paper already cited 1/, that other parasitic bacteria, fungi, and nematodes, as well as insect parasites, are also able to influence beetle abundance. It is the combined action of all these biotic factors with summer rainfall that determines whether there will be an increase or reduction in the beetle population from year to year.

The population changes that occurred from 1944 through 1949 will be described briefly, and the probable influence of summer rainfall in these changes will be pointed out. Records of the United States Weather Bureau have been used in this study.

There were fewer beetles in 1944 than in 1943 in most of the area of general distribution. Exceptions occurred in that part of Pennsylvania along the lower reaches of the Susquehanna River, part of Maryland lying directly south, and an area in central Delaware (fig. 3). Summer rainfall was close to normal in these places in the summer of 1943 though it was much lighter than usual in most of the infested areas.

Beetle populations in 1945 were greatly reduced from those of 1944 in most of the area of general distribution. The greatest reductions in numbers occurred in Rhode Island, southern Connecticut, and the vicinity of New York City, including Long Island and northern New Jersey. Beetles were also less abundant in southeastern Pennsylvania, northern Delaware, and the Eastern Shore section of Maryland and Virginia. Beetle populations were still high along the lower Susquehanna

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3/ Hadley, C. H. Milky Disease for Control of Japanese Beetle Grubs. U. S. Bur. Ent. and Plant Quar. EC-4, 6pp. 1948. (Processed.)

River in Pennsylvania. The reduction in beetles in 1945 was expected because of a rainfall deficiency in 1944. In parts of the infested area the summer of 1944 was the driest since the beetles became established in the United States 2/.

There was an increase in beetles in most of the infested area in the summer of 1946 (fig. 4). However, in some places which suffered heavy reductions in 1945 as a result of the 1944 drought only a slight increase in numbers could be detected. Rainfall in 1945 was generally favorable for the survival of the soil-inhabiting stages; it was plentiful everywhere in July, which is the month when most eggs and small larvae are in the soil.

In most parts of the area of general distribution beetle populations in 1947 reached the highest point attained in many years. As pointed out by Hawley 2/, beetles were noticeably more abundant in the older infested areas where they had not been destructive for a long time. The highest beetle populations occurred in Delaware, Maryland, and southeastern Pennsylvania (fig. 5). Rainfall in the summer of 1946 was above normal in nearly all parts of the area of general distribution and, as it had also been plentiful in 1945, the high populations in 1947 were attributed largely to the favorable rainfall conditions of the two preceding seasons.

There were fewer beetles in most of the infested area in 1948 than in 1947. Reductions in numbers were especially marked in southern New Jersey, Delaware, and eastern Maryland (fig. 6). Beetles were more abundant than elsewhere in those parts of Maryland and Virginia that lie north and west of Washington, D. C. The changes in numbers in this area in 1948 follow closely the rainfall pattern in the summer of 1947, for rain was deficient in Delaware and the eastern part of Maryland and Virginia, but normal or above in western Maryland and Virginia.

A high milky disease incidence appears to have occurred in 1948, following the high grub populations of 1947. In some localities, the reduction in beetle numbers in 1948 was doubtless due to the rainfall deficiency in 1947. Reductions in certain other places cannot be attributed to this cause, and it is believed that milky disease and other biotic agents were responsible for the lower populations. It is known that the parasitic spring Tiphia, *Tiphia vernalis*, was more active and destructive following the high beetle grub populations of 1947 than it had been for several years. There is also evidence that certain other parasitic forms were more active in 1948 because of the higher larval populations.

There were fewer beetles in 1949 than in 1948 in the northern, and some of the southern parts of the beetle-infested area. There were rainfall deficiencies in August and September 1948 in New England, New York, and parts of Pennsylvania that resulted in reduced populations there. As rainfall in this same area in the summer of 1949 was the lowest in many years, it is expected that the already low beetle populations will be still further reduced in 1950. There were more beetles in western Maryland, the part of Virginia to the south, and in eastern West Virginia in 1949 than elsewhere in the infested area. Rainfall was close to normal there in 1948, and as rainfall was again favorable in the summer of 1949, there

should be many beetles in this area in 1950. In some parts of the southern infested area beetles did not increase in numbers in spite of a favorable rainfall condition. This is probably due to the continued high activity of biological control agents.

This study has shown that if summer rainfall is highly favorable it is sometimes possible for the Japanese beetle to increase to destructive numbers in spite of the action of other restraining factors.

The area continuously infested by the Japanese beetle will continue to grow each year, and the insect will be meeting new climatic conditions and new ecological influences. It will be possible to help in the control of the insect in these new areas by introducing the milky disease, insect parasites, and possibly other biological control agents. It will be possible to determine the normal summer rainfall in these new areas from Weather Bureau records, but it will take time to determine how the insect will react to the extreme deficiencies or excesses in rainfall that occur in the new places. It will be the reaction of the beetle to all these factors in the new habitats that will govern its status as a pest.

STATUS OF THE JAPANESE BEETLE IN THE ISOLATED COLONIES OF THE OUTER ZONE

In the outer zone, beyond the limits of the area of general distribution, the Japanese beetle occurs in isolated colonies of various sizes. In some of these, shown by the larger dots on figure 1, beetles have spread over large areas and are numerous enough to cause considerable damage by their feeding. Residents of such areas have learned to live with the beetle with the help of biological control agents and insecticidal treatments which are now available. In other places, marked by the small dots on figure 1, the infested areas are usually small and beetle feeding is generally of little or no importance. As would be expected, these isolated colonies are usually more numerous and larger close to the edge of the area of general distribution than they are at more remote points.

Each year the Division of Japanese Beetle Control of the Bureau of Entomology and Plant Quarantine carries on a trapping and suppression program in cooperation with entomological agencies in the States of the outer zone. Traps are operated at many places, first to determine whether beetles are present, and then to obtain information on changes in numbers from year to year. Beetles have been found; at only a few of the many places where traps have been used. In many of the lightly infested areas beetles are kept under control by treating the soil with poison to destroy the larvae; spraying of the food plants with DDT is also carried on in some areas to kill the adults. These measures have been highly effective and have often resulted in the destruction of all, or nearly all, of the beetles in these colonies.

At many of the more distant points, marked by dots on the map (fig. 1) only 1 or very few beetles were originally found, and none can be found at many of these places at the present time. Over a period of years only 2 beetles have been taken at the one location in Iowa, 21 at the five places in Tennessee, and 24 at five locations in Florida. In the summer of 1948 only 55 beetles were taken in the State of Missouri, 45 in Indiana, and 93 in Illinois. The growth rate of small isolated colonies varies but, in general, dispersion and build-up are slow at first and then increase at an accelerating rate as the colony grows older. It is evident that if known and proven control measures are applied when colonies are small it will usually be possible to postpone for many years the time when the destructive feeding habits of the Japanese beetle must be combatted or endured.

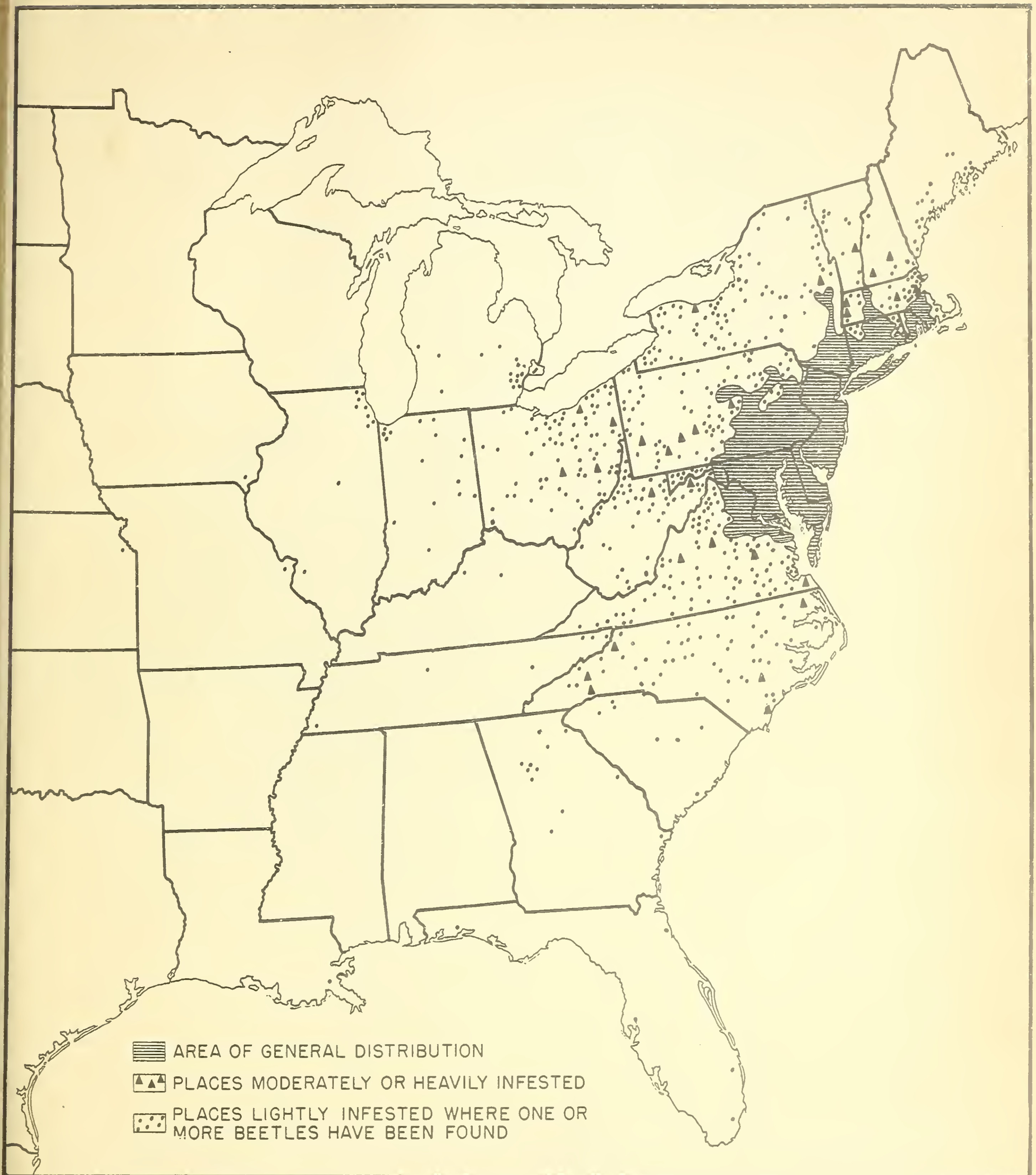

FIGURE I. PLACES WHERE THE JAPANESE BEETLE HAS BEEN FOUND THROUGH 1949.

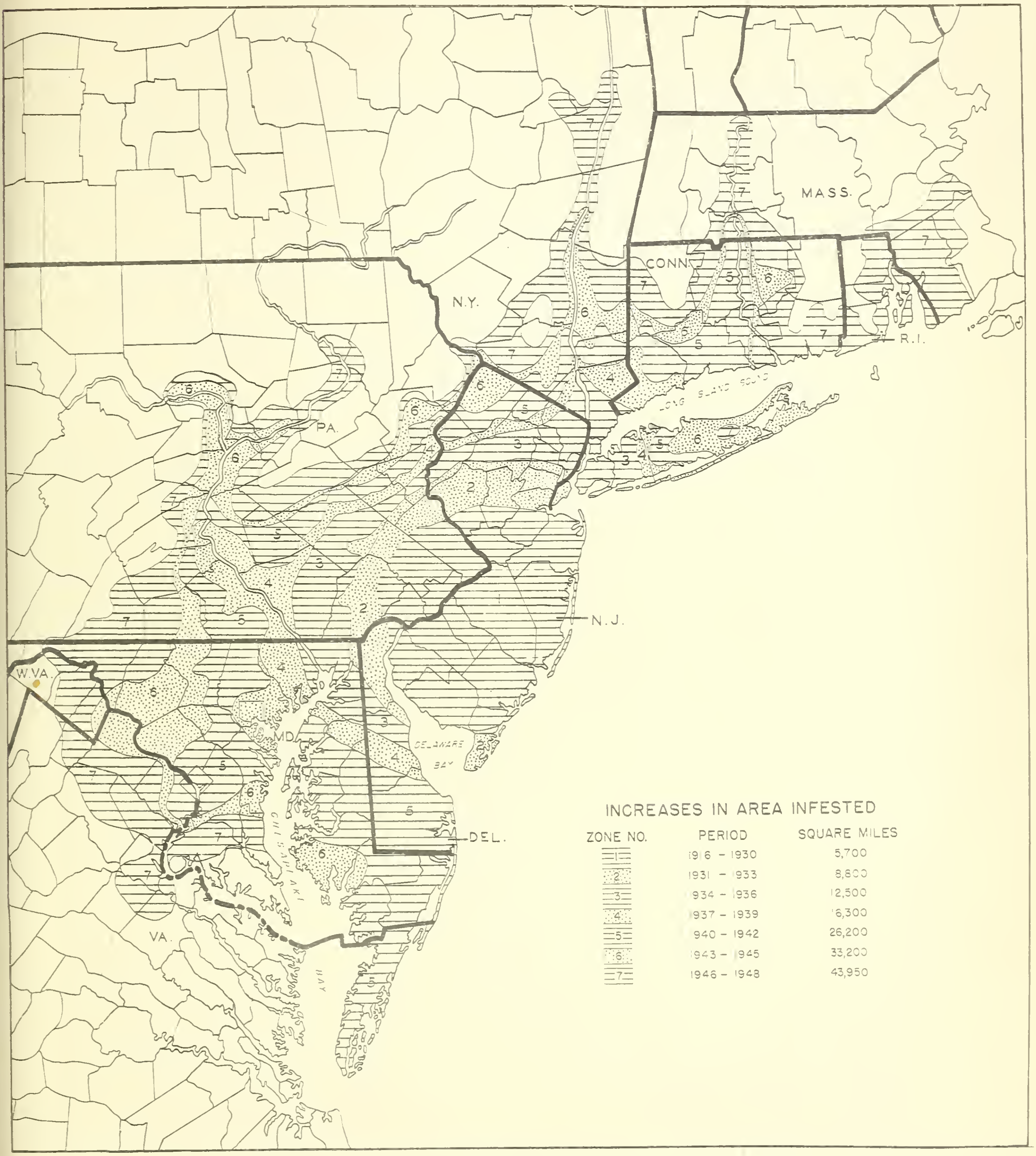

FIGURE 2. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE, 1916-48.

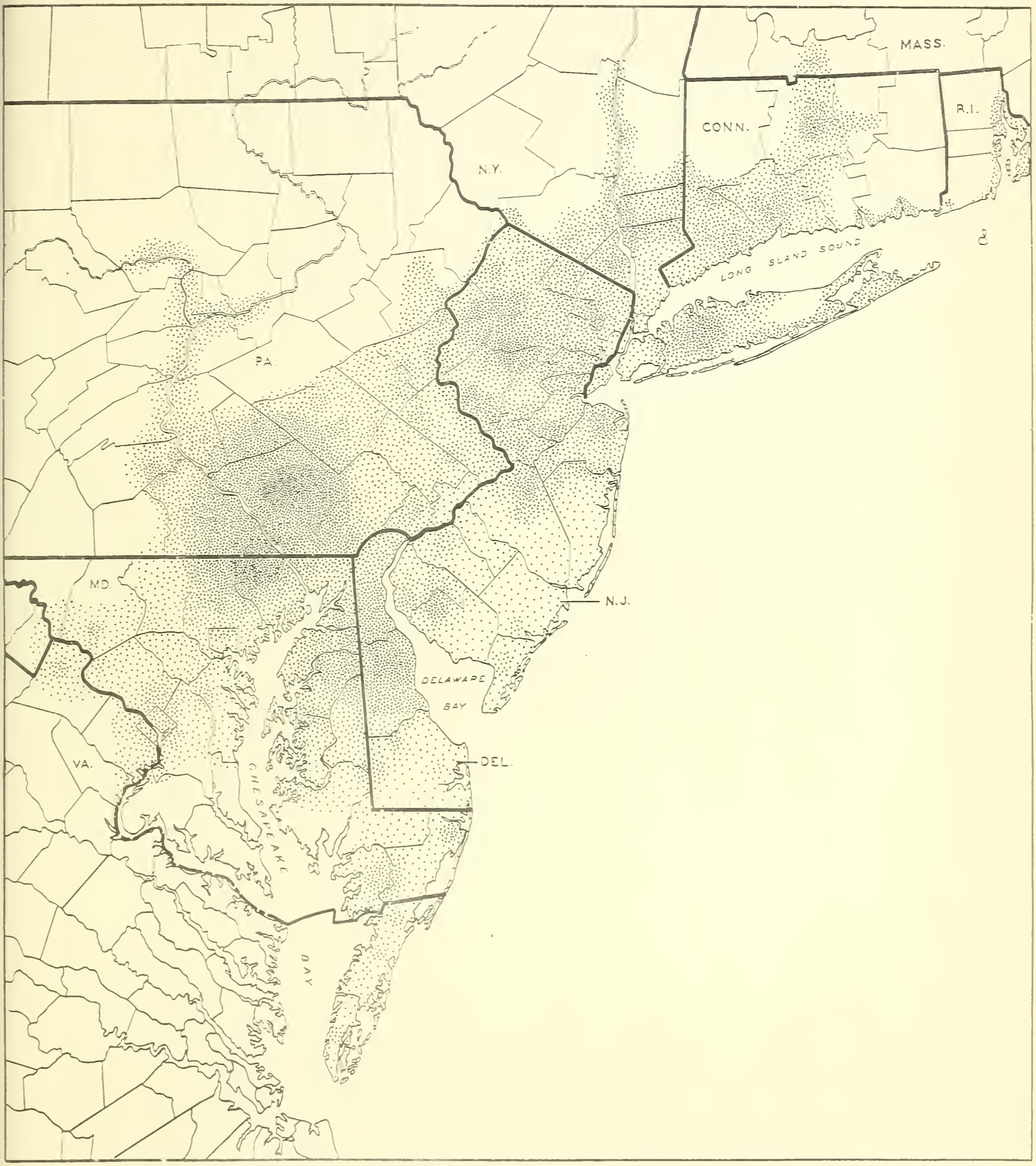

FIGURE 3. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE IN THE SUMMER OF 1944.

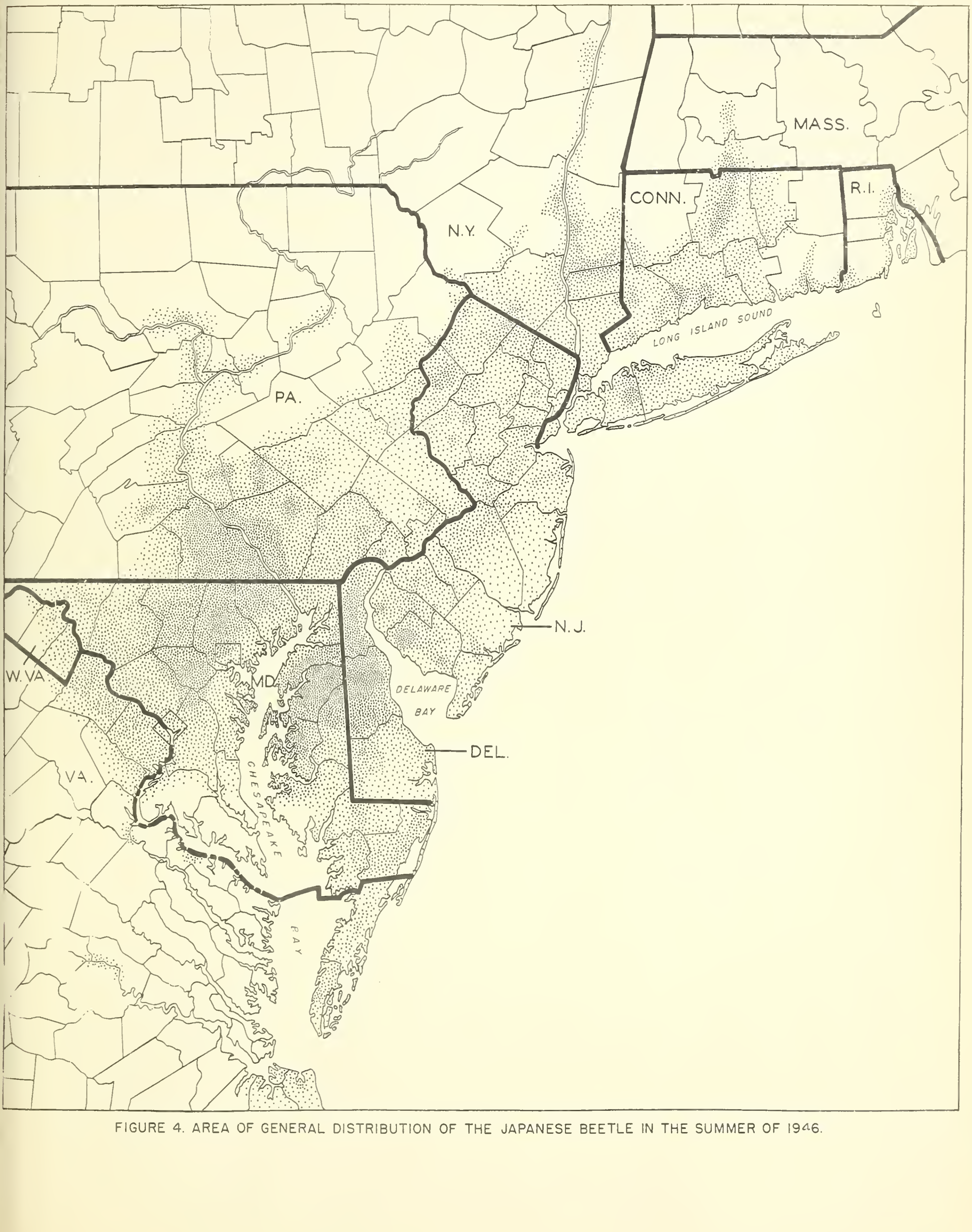

FIGURE 4. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE IN THE SUMMER OF 1946.

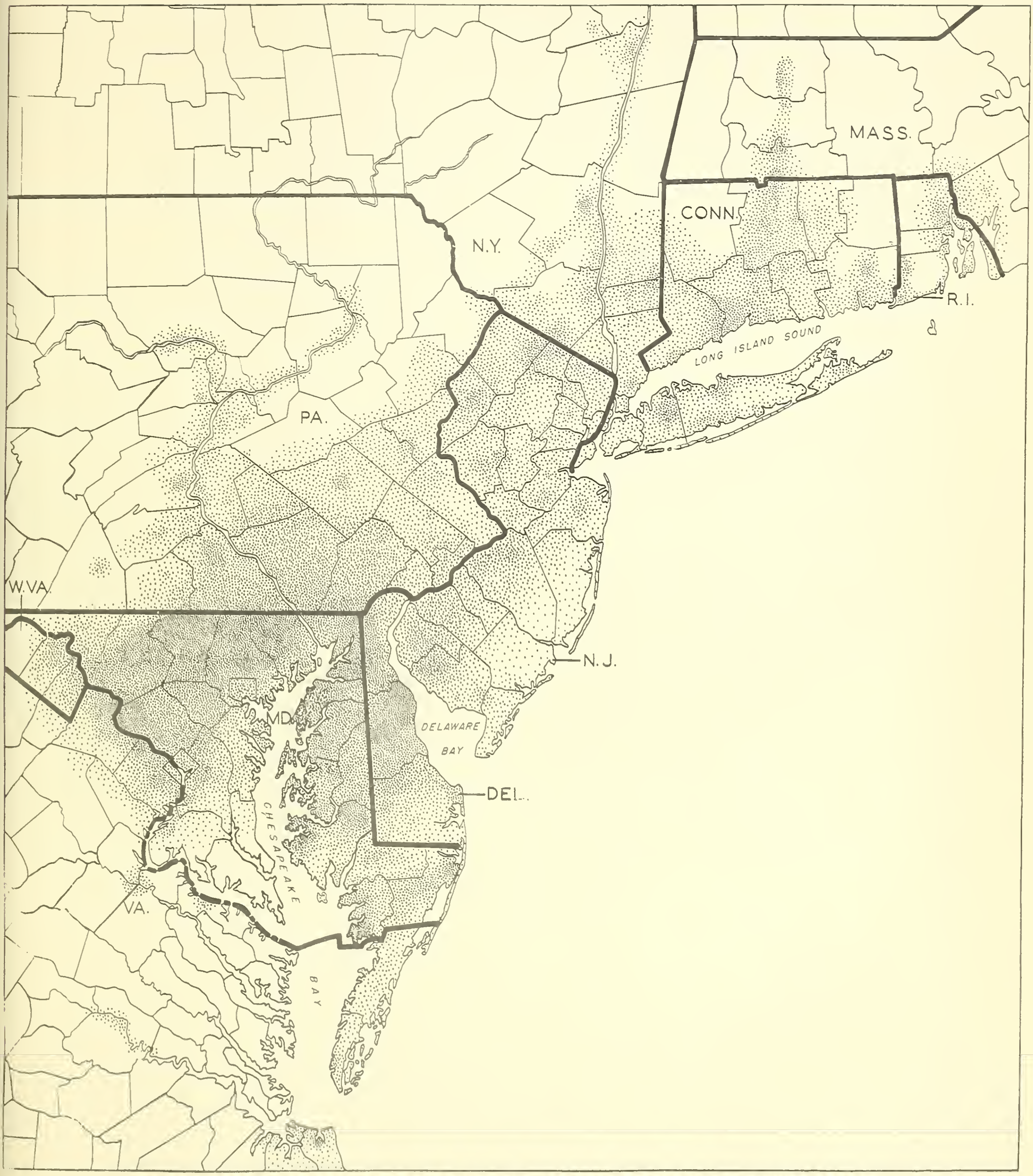

FIGURE 5. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE IN THE SUMMER OF 1947.

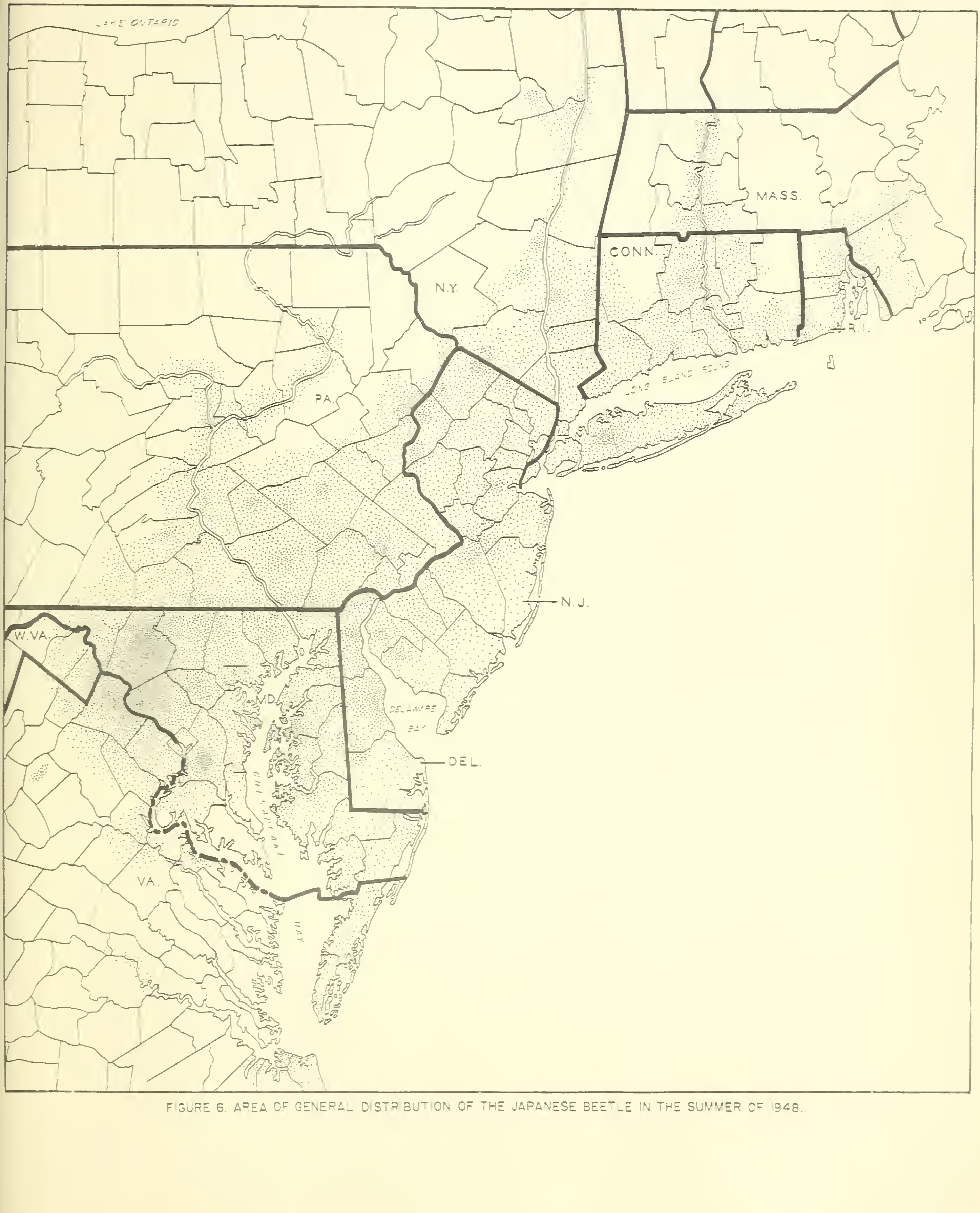

FIGURE 6. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE IN THE SUMMER OF 1948.

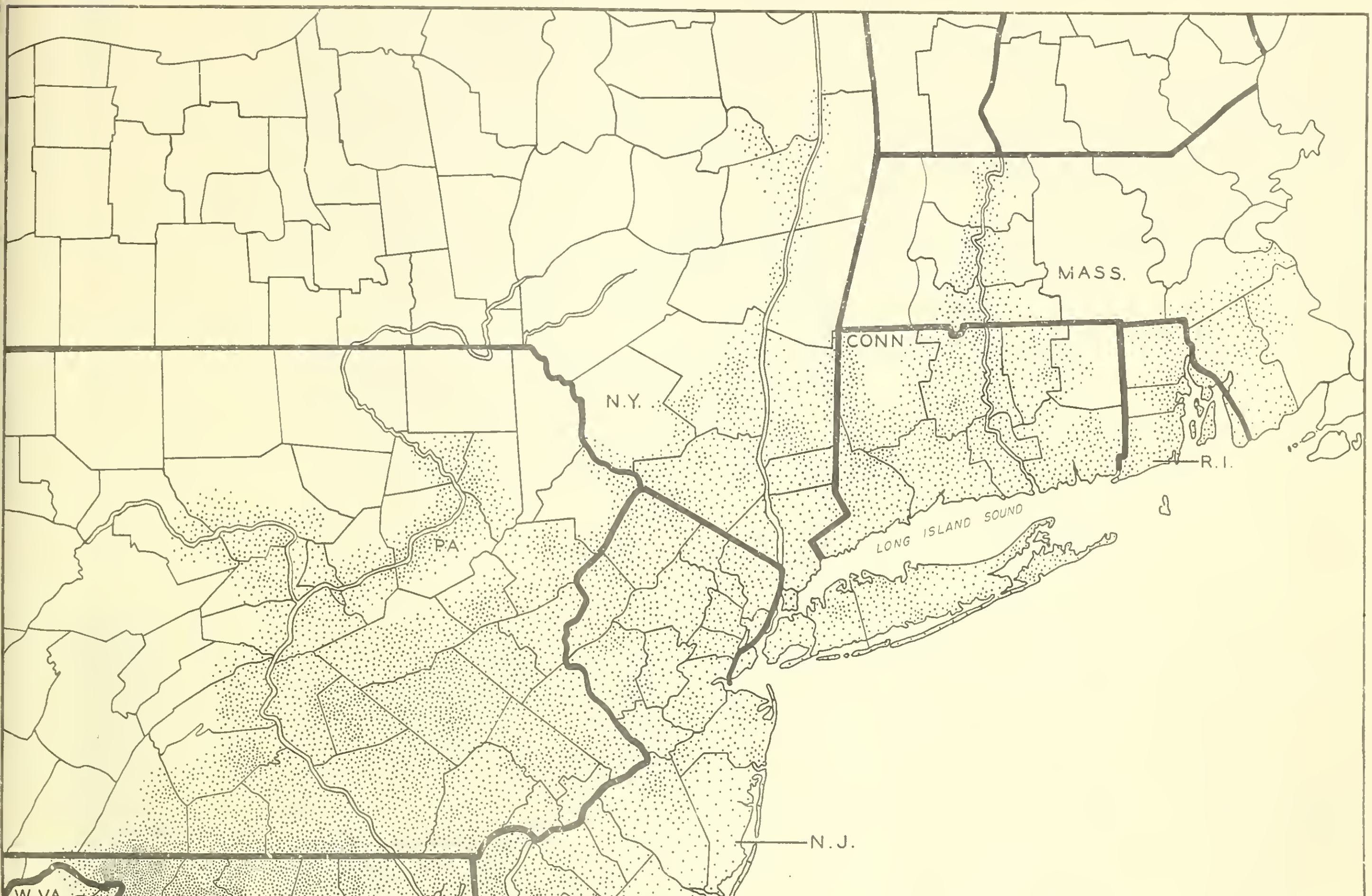

FIGURE 7. AREA OF GENERAL DISTRIBUTION OF THE JAPANESE BEETLE IN SUMMER OF 1949.